interference of these currents at the intermediate surface breaks up the lower surface, or perhaps even the whole of the horizontal wedge of descending stratus, into rolls (or cumulo-stratus stretching horizontally in imitation of rolls) whose axes stretch from some northerly point to the opposite southerly point; the exact trend depends upon the relative strength of the upper and lower current. If the lower is the stronger, the trend will be southeast rather than southwest, and as stronger winds are nearer the lowest pressure, therefore the trend will vary with the distance from the center of low pressure around which these winds and clouds are circulating. If this center is near at hand and bears northwest from the observer, and if it is moving eastward, and especially if the observer's wind is south and the lower cloud motion from the southwest while the trend of these cloud rolls, or the perspective vanishing point of the parallel striæ on the lower surface of the sheet of stratus above the observer be east and west, then the region of heavy cloud and rain will probably not move or extend southward to his station, but passing eastward, will probably keep to the north of him. If the barometric depression is a long trough, these relations are modified and the rain may reach him. If the trend of the axes of the rolls is from southwest to northeast and is then soon observed to change so as to become northwest and southeast, this indicates that the clearing region is rapidly approaching with its cooler air and that there is less prospect of rain.

But as these phenomena are affected by the topography of of the surrounding country, therefore such rules for Washington may not apply strictly to another locality, and the Editor will be pleased to publish such rules as others may have deduced.

HOAR FROST ESPECIALLY RICH IN NITROGEN.

(Translated from A. LANCASTER in Ciel et Terre, XVII, p. 54.)

Messrs. Petermann and Graftiau in a memoir, published by the Academy of Sciences of Belgium, and entitled Researches on the Composition of the Atmosphere, demonstrate the special richness of hoar frost in nitrogenous compounds, and draw attention to the important part that hoar frost plays in adding to the stock of nitrogenous matters in the forest, as well as to the purifying influence that the forests exercise on atmospheric air.

The truly remarkable richness of hoar frost merits attention as one of the interesting points in the complicated mechanism of the circulation and distribution of nitrogen throughout the world. The frost work which is attached to the branches of trees presents to the air, which surrounds it and is continually renewed, a large surface for the absorption of all the soluble bodies that it carries, and the isolated trees, the plantations, and the forests act like immense filters purifying the air that circulates through their foliage, robbing it of those nitrogenous combinations which, being returned to the soil by a thaw, serve again as nutriment to the plants and thus reenter the vital cycle. When one sees the branches of the trees bending under the weight of the frost, when the latter accumulates to the point of breaking the larger branches, we should recognize that this represents an appreciable factor in the stock of nitrogenous material accumulated in the forests.

The following analyses of one liter of melted frost collected at Gembloux, Belgium, are given in the above work:

	Milligrams of nitrogen.
March 1, 1889	5.86
January 2, 1890	7.70
December 31, 1890	9.00
December 31, 1890	8.00
December 31, 1890	7.02
Average	7.52

During the severe cold of the winter 1894–95, M. Graftiau made some further measurements for the purpose of also taking account of the quantity of frost actually attached to the branches. On February 7, between 9 and 10 a. m., and at a temperature of 16° C. below zero (plus 3.2° F.) he collected the frost attached to different species of trees growing in the arboretum of the agricultural institution at Gembloux. The branches that were heavily ladened with frost were gently detached and then shaken over a sheet of paper. The frost was then collected in a dish and weighed. In this way we could only obtain a part of the frost, therefore, the figures cited below are the minima. The quantities obtained were as follows:

Species.	Weight of—		Surface of branch.
	Frost.	Branches.	
	Grams.	Grams.	Sq. cm.
Cornus sanguinea	2.0	2.0	30
Populus alba	2.8	3.6	36
Ribes saxatile	5.5	2.5	100
Salix alba	34.1	15.0	203
Salix vitellina	39.3	32.1	270

Graftiau also weighed the frost on an entire shrub (*betula rotundifolia*). The cube limited by the extremities of the branches was about 1.5 meters on a side; the weight of the frost was 1.755 kilograms. The melted frost was analyzed and each liter contained: 4.0 milligrams of nitrogen as ammonia and 1.2 milligrams of nitrogen as nitrates and nitrites, or a total of 5.2 milligrams of combined nitrogen.

This frost of February 7 was not at all remarkable, and yet we see that its weight exceeded 1 kilogram for each cubic meter of space occupied by the branches. In mature forests the branches occupy, at a low estimate, a space of about 100,000 cubic meters to the hectare, and can, therefore, collect 100,000 kilograms of frost which represent, approximately, half a kilogram of combined nitrogen, if we adopt as the base of our calculation the small amount of frost that collected on the branches during the severe frost of February 7. If, for an average, we take 7.5 miligrams instead of 5, the deposit would be nearly 800 grams of nitrogen to the hectare, or 7 pounds to the acre.

Frost is sometimes formed to an extraordinary amount. It is then capable of breaking by its own weight branches that are 10 centimeters in diameter, which happened some years ago in different parts of the country. Therefore, the quantity of nitrogen that is given to the soil by the frost that falls on it is very considerable.

These authors, therefore, have with good reason said that the frost represents an appreciable factor in the reserve of nitrogen within forest areas. If we add to this the nitrogen contained in the rain, the dew, and the fog, we can easily explain why, without any artificial addition of nitrogen and without the intervention of those plants that serve to fix atmospheric nitrogen, the forest vegetation is always well supplied with nitrogen, and it also shows how the soil of forest areas grows richer in this element which is given to it by the detritus, or the waste of the forest.

[May we not also suggest that the stunted foliage on the summits of mountains, fed as it is by the melting of frost and snow, may be peculiarly well supplied with nitrogen.—C. A.]

ATMOSPHERIC REFRACTIONS AT THE SURFACE OF WATER.

In response to an inquiry about mirage, the Editor has collected the following notes from recent publications:

Prof. Charles Dufour of Lausanne communicated to the Academy of Sciences at Paris a memoir, of which Mr. Lancaster (*Ciel et Terre*, April, 1896, Vol. XVII, p. 88) gives the following summary—

Abnormal refractions are often observed on Lake Leman [*i. e.*, Lake Geneva, Switzerland]. If the air is colder than the surface water we have conditions favorable for mirage; the path of the curved ray of light turns its convex side toward the water and mirages are formed as beautiful as any that occur over a desert. On the contrary, if the air is warmer than the water then the path of the ray of light turns its concave side toward the water and we then see distant objects that are ordinarily concealed by the rotundity of the earth, *e. g.*, the curved surface of the lake or of the ocean. In this latter case, for example, the Chateau of Chillon can be seen from Morges, distant 35 kilometers. Under normal conditions as to the temperature of the air the chateau is concealed by the curvature of the lake and would be so even if its height were doubled. It follows, from this, that if the air is colder than the water, which is generally the case in winter, the visible or apparent horizon line appears depressed by a quantity greater than the average depression; on the contrary, when the air is warmer than the water, which often happens in the summer, the depression of the horizon is less than the average. The author (C. Dufour) inquires whether this cause of error is considered when a navigator at sea observes the altitude of the sun above the horizon in order to determine the latitude or time. If he does not, this omission must cause appreciable errors in the computed positions of vessels on the ocean. According to observations made at Morges, it is certain that this difference of temperature at the point where the tangency to the surface of the water occurs sometimes produces errors that exceed five or six minutes of arc in the apparent altitude. He thinks that tables correcting for this error should be prepared.

Although this abnormal refraction is not vitally important in navigation, owing to many other sources of errors that affect the determination of the position of the vessel at sea yet, from a meteorological point of view, it is always important to understand the minutest details of what is going on in the atmosphere. The phenomena of the mirage here alluded to occur on the Great Lakes of North America in all their intensity in the summer season, and it is well for the observer to bear in mind the simple rule that when the mirage brings to his view objects otherwise invisible it proves that the temperature of the air through which the lowest part of his line of sight is passing is higher than that of the layer just below it, as the latter is cooled by contact with the cold water. When a slightly denser mass of air descends to the surface of the land or water, and, rolling along, finally spreads as a cool layer over the heated surface it temporarily breaks up the mirage due to hot air and substitutes that due to cold air, but in doing so both air and water are slightly agitated and this agitation produces the beautiful fleeting mirage called "fata morgana." Such phenomena must be very frequent on our American lakes, both large and small, and the Editor would be glad to have some account of them and a comparative study based on the current daily Weather Map.

In continuation of the above subject Prof. F. A. Forel communicated to the Paris Academy of Sciences (*Paris Comptes Rendus*, July 20, 1896, CXXIII, p. 161) the following note on the refractions and mirages on Lake Geneva:

The opposite types of refractions to which the rays of light are subjected when they graze the surface of the lake depend upon the relative temperature of the water and the air in contact with it. They are:

(1) The *refraction above warm water*, when the air is colder than the water. These refractions are characterized by the contraction of the horizon from all sides toward the center, by the exaggeration of the apparent curvature of the spheroidal surface of the lake, by the appearance of extraordinary denticulations or waves at the horizon line, finally, by the formation of a symmetrical mirage below that which we call the caustic plane; this mirage offers an apparent reflection of objects situated beyond the circle of the horizon, and is, therefore, the so-called mirage of the desert.

(2) The *refractions above cold water* when the air is warmer than the water. These are characterized by the enlargement of the circle of the horizon, the appearance of greater concavity which is assumed by the spheroidal surface of the lake, the elevation of the apparent horizon, the visibility of very distant objects that are really hidden by the rotundity of the earth, finally, the vertical shortening of objects that are very low down on the water and at a great distance.

(3) Between these two opposite types there are other special apparitions known under the name of fata morgana, fata brumosa, and, finally, the still unexplained phenomenon of the mirage over cold water, which occurs whenever the temperature of the air rises steadily above the temperature of the water. The mirage above cold water has the same characteristics as the mirage due to refraction above warm water, except that the lower image is not symmetrical, it is indeed inverted as to the real image, but it is greatly reduced in its vertical dimensions, often it has not a third of the height of the real object (See F. A. Forel, *Le Leman*, 2d volume, Lausanne, 1895.)

I have endeavored to precisely describe the conditions under which these various types appear. This is the result of very many observations, made for the most part on Lake Geneva. In order to simplify I will take my examples from a day in spring. At this season the temperature of the air runs through all possible variations with respect to the temperature of the water, and every type of refraction can appear in succession. In the morning, let us say at 6 a. m., the air cooled during the night is colder than the water of the lake. We then see the refractions and mirages over warm water. Toward 10 a. m., or noon, the temperature of the air rises, then it equals and finally exceeds that of the water, then we have the mirage over cold water. In the afternoon, between 2 and 4 p. m., suddenly the refractions change their character; the convexity of the lake is transformed into an apparent concavity; we see then the apparition of the fata morgana and sometimes that of the fata brumosa which persist for a few minutes only. I think I have proven that the appearance of the palaces of the fata morgana are only seen in all their beauty when a slight breeze passes over the lake after a morning of perfect calm.

Then suddenly we change. As soon as the fata morgana has disappeared the refraction over cold water takes possession of the scene and lasts until nighttime. The series of refractions is, therefore, as follows: (1) Mirage over the warm water; (2) mirage over cold water; (3) fata morgana; (4) refractions over cold water. The fata morgana occupies only a limited segment of the circle of the horizon; on one side of its fantastic apparitions we see the régime of the mirage over cold water, on the other side the refractions over warm water without mirage.

A further contribution to this subject will be found in a note by M. Andre Delebecque (*Paris Comptes Rendus*, August, 1896, CXXIII, p. 387) "On the extraordinary refractions observed on the borders of lakes and known by the name of fata morgana." He says:

In general this phenomenon is characterized by the fact that objects situated on the opposite shore of the lake seem to be distorted in an extraordinary way in a vertical direction; the rocks, the walls, and the houses appear to be transformed into immense constructions, out of which the imagination of the Italians has evolved the palaces of the Fairy Morgana. The fata morgana are extremely fleeting phenomena and do not generally last more than a few minutes. When they disappear the object whose vertical dimensions had been so magnified often assumes extraordinarily small proportions. As both Mr. Ford and myself have observed, the fata morgana occupies only a very limited and perpetually changing segment of the horizon, and quite near to it entirely different refractions frequently take place. On Lake Leman I have only observed them in calm weather and when the temperature of the air is notably warmer than that of the lake. They are most beautiful in the months of March, April, and May.

Many scientists, among whom I may cite Humboldt, Woltmann and Charles Dufour, have spoken of the fata morgana, but up to the present time, as far as I know, no one has given a satisfactory explanation of it, for when the air is warmer than the water of the lake, we sometimes observe the fata morgana, but more often the mirage known under the name of "mirage over cold water" and which has been so well studied by Bravais (see Bravais, *Notice sur le Mirage, Ann. Met. de France*, p. 256, 1852). In this latter mirage distant objects have their vertical dimensions much reduced. It seems singular that the same thermal conditions should produce two mirages so diametrically opposite to each other. The following is, I believe, the correct explanation of this apparent anomaly:

Many times when viewing the fata morgana through a powerful glass I have observed that the objects are not really increased in size, but that the impression is produced by the superposition of several images of the same object, sometimes upright, sometimes upside down. I have counted as many as five of these images. As they are generally very close together and sometime encroach one upon the other, it is very difficult to separate them by the naked eye, and therefore the illusion of an enlarged object is produced. Sometimes one portion alone produces many images. Thus, I have sometimes seen boats with two hulls, while the sails looked perfectly natural; a few minutes later only one hull remained, but the sails appeared gigantic.

It seems to result from these observations that the fata morgana is nothing more than a mirage of multiple images.

Mathematical analysis can, however, explain the facts observed.

In his memoir on the mirage, Bravais (see Bravais, *Notice sur le Mirage, Ann. Met. de France*, p. 264,) proves the possibility of three images being produced in the case where a layer of warm air flows more or less suddenly over a layer of cold air and when the subsequent calmness of the atmosphere allows these two layers to remain for some time in that position. But these are precisely the conditions existing during the apparition of the fata morgana, since it is necessary, as I said above, in order to produce this phenomenon that the air be very calm and perceptibly warmer than the water. The existence of three images is a particularly simple occurrence in the fata morgana. I have tried to explain, by analysis, the production of the five images observed by me, but was obliged to give it up on account of the complexity of the calculations. In the case of three images, Bravais also shows how only certain parts of an object can produce multiple images; this phenomenon actually occurs as we have seen above.

Finally, if we reflect that two layers of air of very different densities cannot remain for a long time superposed one upon the other without becoming mixed, we shall understand the instability of the phenomenon and why the fata morgana and the mirage on cold water can succeed each other so rapidly in the same part of the lake.

An excellent description of the fata morgana as seen from Reggio, on the Italian coast, when looking toward Messina across the Straits of Messina, is given by Mascart in the third volume of his Treatise on Optics, Paris, 1893. In this volume (pages 305-338) he also gives a complete elucidation of the optical principles involved in every form of mirage, including even the triple images of vessels in the distant horizon, the multiple images observed by Arago and Biot, and every form of fata morgana. Mascart's formula seems to us applicable to all the cases enumerated in the above quotations.

AN EXPERIMENTAL RAINFALL.

A letter of June 20 from Prof. L. Errera, of Brussels, is published in *Ciel et Terre* for August, 1896, XVII, p. 353, giving the following description of an experimental study into the formation of clouds, which will, we hope, attract the attention of physicists who are conducting advanced courses in meteorology in American colleges and universities. The experiment has been repeated at the Weather Bureau with success, but it should be carried out on a large scale, with a very tall jar and great care as to uniformity of temperature, if one desires to get satisfactory results. Probably the clouds can be photographed by using a flash light and with care in the illumination. Other liquids, such as ether, benzine, turpentine, and water, should also be tried:

Take a cylindrical vase of bohemian glass of about 20 centimeters in height and 12 in diameter and fill it half full of strong alcohol—92 per cent—and cover it with a porcelain saucer and warm it over the water bath. It is necessary to warm it up for quite a long time, in order that the liquid and the whole vase and the porcelain cover may attain a high temperature and be in thermal equilibrium among themselves, but without bringing the alcohol to the boiling point. Remove the whole from the warm place and, being careful not to agitate the liquid, place the vase upon a wooden table and observe it carefully. The warm liquid continues to send up an abundance of alcoholic vapors. After some minutes the porcelain cover is sufficiently cooled so that these vapors commence to condense in its immediate neighborhood. Soon there are thus formed clearly visible clouds, and these in their turn resolve themselves into very fine droplets of rain, which fall steadily, vertically, and in countless numbers into the liquid. The droplets, when measured by means of a horizontal microscope, have an average diameter of from 40 to 50 thousandths of a millimeter; they are sometimes larger but more frequently smaller. This interesting spectacle may last for half an hour.

At first the vapors rise quite up to the porcelain cover, but in proportion as the whole system cools down the level where the condensation occurs naturally lowers more and more, and now we find a perfectly clear zone above the zone of clouds. We have in this way in miniature the whole aqueous circulation of the atmosphere; the evaporating liquid represents the ocean, far above it the cooling porcelain saucer is the pure sky, below this the clouds, which resolve themselves into real water, and the latter returns to the ocean. Except that in place of water everything is made of alcohol.

It would be surprising if this simple phenomenon has never been described before; but as you say that you do not remember to have seen an account of this anywhere in the meteorological literature, with which you are so perfectly familiar, I think it well to explain the conditions under which the phenomena are produced.

[The experiments here described by Errera may be compared with the well-known similar work of Tyndall and Aitken, especially those described by the well-known physicist of Edinburgh in his memoir entitled "On dust, fogs, and clouds." (Edinb. Transactions, 1880-81, XXX.) But Aitken makes use of complicated apparatus, while the experiments of Errera can be repeated at any time and in the simplest manner. Moreover, Errera describes very interesting phenomena that Aitken did not perceive, or, at least, has passed over in silence. Tyndall considers an analogous subject in his note "On the formation and phenomena of clouds." (Roy. Soc. London Proceedings, 1869, XVII.)—A. LANCASTER.]

Possibly this experiment may serve to explain some meteorological problems that are still under discussion; for example, whether the production of rain is necessarily subordinated to electrical influences, as is acknowledged by Clement Ley and many other authors.

Our experiment is, moreover, susceptible of several variations. After having taken the vase from the warm bath, if we replace the warm porcelain cover by a cold one the differences of temperature between different points of the system become greater and the phenomena are exaggerated; little whirlwinds, which are true squalls, are produced. When the alcohol is still very warm and if, by accident, the vase is a little warmer on one side than on the other, in that portion which is above the level of the liquid we see the alcoholic vapor performing a regular rotation about a horizontal axis; it continually rises along the warmer side of the vase and descends along the colder side. The proof that this rotation is due to the cause that I suggest is, that in order to reverse the direction of the rotation it suffices to cool the side of the vase along which the vapors are rising and this is easily done by the application of a strip of filter paper wet with cold water and frequently renewed.

At first thought the formation of cloud and rain in Errera's experiment where there can be no dust particles to serve as nuclei for condensation, seems to be contrary to Mr. Aitken's theory and experiments, according to which all ordinary rains and clouds depend upon the presence of dust nuclei; but there is really no contradiction. When air is cooled to a temperature near dew point, condensation begins where it is most easily possible, viz: first, on hygroscopic surfaces and next to this, on small particles of dust, many of which are also hygroscopic and, finally, on those that are smallest, even though they be not specially hygroscopic. If cooling proceeded only thus far, we should have dew, fog, and cloud, but no rain. If the process of cooling still continue then a certain critical stage is passed over and the aqueous molecules begin to agglomerate without waiting for the presence of nuclei; they come together in larger drops and by a more violent process. The extent to which cooling must proceed in order that this form of condensation may begin has been investigated, and may be defined as follows: If the cooling is produced by expansion, then the amount of expansion required in order to produce the second stage of condensation is 1.258 times the expansion necessary to produce the first stage of condensation. (See MONTHLY WEATHER REVIEW, May, 1896, page 167.) As long ago as 1841 Espy (see his Philosophy of Storms, page 35) observed the fact that when, by expansion, we determine the dew-point for a mass of air contained within a glass jar, several times in succession, the dew-point seems to be steadily rising. He says:

On comparing together the experiments made on dry air, there appeared but little discrepancy, but with moist air this was not so, and I was induced to institute a set of experiments to see whether length of time had any influence on the result. I, therefore, performed a great number of experiments similar in all respects, except the length of time which intervened between the time of pumping air into the nephelescope and of letting it out, and, to my astonishment, I found the rise of the mercury, after the discharge, constantly greater as the time was longer, up to about twelve or fifteen days; but beyond that time the effect did not seem to be increased. It follows from these experiments that when air saturated with vapor is confined in a glass vessel, air-tight, and containing a small portion of water, it will cease to be saturated to the amount of four or five degrees in the dew-point in fifteen days. Whatever may be the cause of this remarkable fact, so contrary to all our notions, since the experiments of Dalton on the subject of the dew-point, the following table of experiments proves beyond all doubt that it is a fact. Does water or glass so attract the particles of aqueous vapor as to condense some of these particles on them and bring down the dew-point four or five degrees below the temperature of the water and of the air included in the vessel?

The Editor can not doubt that Professor Espy was here in presence of the phenomenon that has subsequently been investigated by Barus and C. T. R. Wilson. By allowing his air to stand so long it had, by washing and settling, lost the greater part of its original dust. The dew-point determined by Espy, at the beginning of any experiment, corresponded to the first stage of cooling and the formation of fog on dust nuclei; but the dew-point determined by him a few days later in the same air when it had become dustless by settling